Photochemical Reactions as Key steps In Organic Synthesis.

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Seminaire 29.05.08

Contents

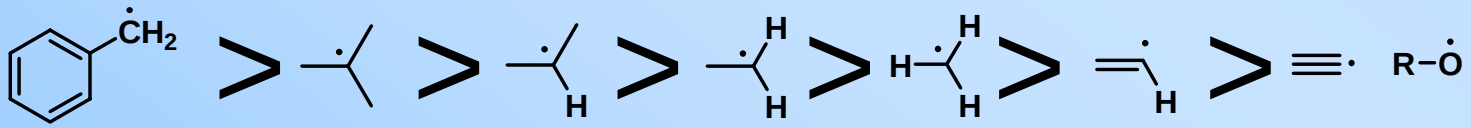
Introduction

Generalities :

2 options to induce radical reactions :

- Photochemical (light as energy source) : hν
- Thermochemical (Δ as energy source) : peroxyde, diazo…

Radical stability :



85 kcal > 91 kcal > 95 kcal > 96 kcal > 100 kcal > 108 kcal > 110 kcal

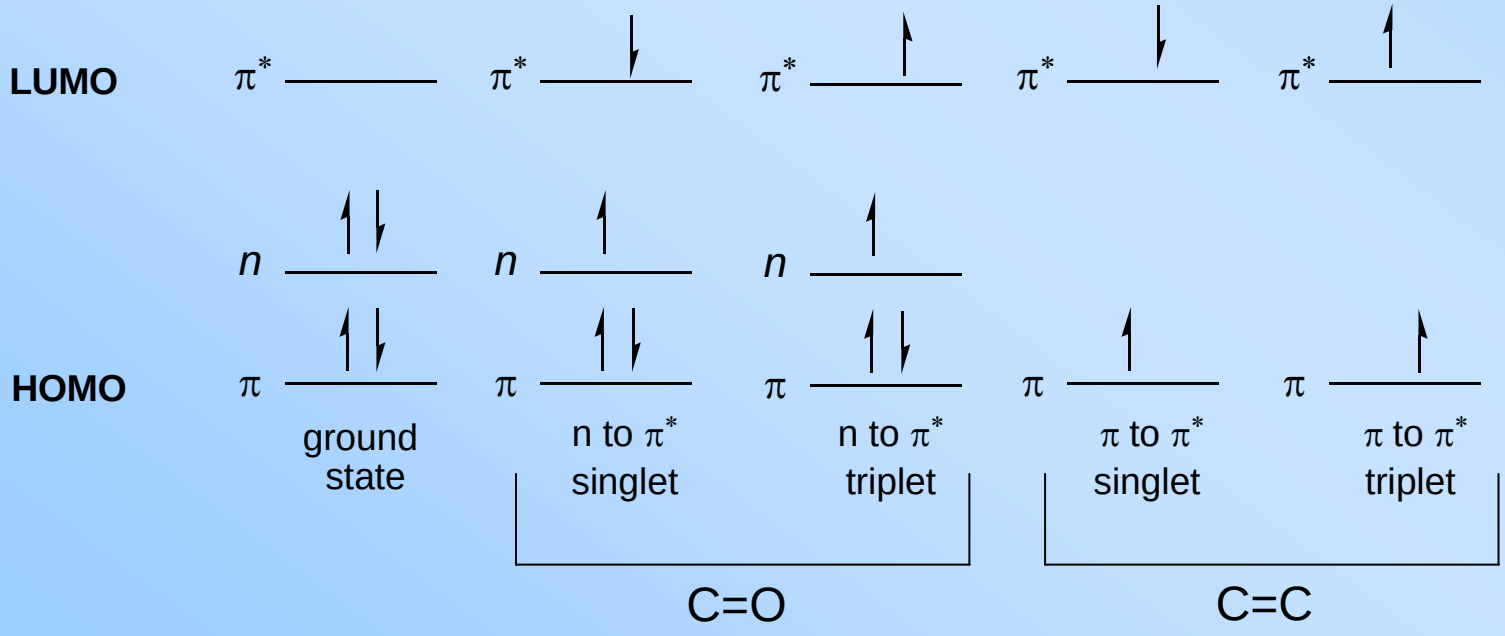
Introduction

Photochemistry :

- initiated by light
- Chemically useful light is generally in the range of 200-400nm
- Absorption of a photon induce an electronic transition

(ground state ⟶ excited state)

usually C=O and C=C



Introduction

Rayonet (New England Ultraviolet & Co)

external irradiation

Immersion hν reactor

Internal irradiation

Introduction

Why using photochemical reaction in total synthesis ?

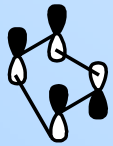
advantages :
- obtention complex, polycyclic, or highly functionalised structures
- form thermodynamically disfavoured products
- diminish formation of byproducts
- often occurs without additional reagents
- the reagent is cheap (sunlight), easily accessible and renewable

constraints :
- wavelength choice
- reactivity is often unpredictable
- many substrates are not compatible
- solvant choice
- material expensive

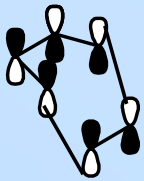
The Woodward-Hoffmann-Fukui rules of cycloadditions

Number of Electrons	Mode of activation	Dewar-Zimmerman
$4n$	thermal photochemical	suprafacial (pair) antarafacial (impair)
$4n + 2$	thermal photochemical	antarafacial suprafacial

n : an integer



[Π2s + Π2a]
antarafacial



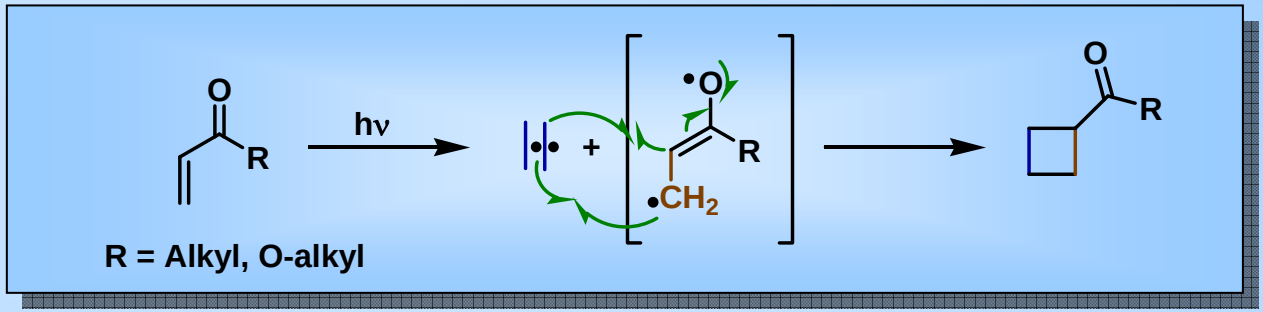
[Π4s + Π2s]
suprafacial

(a) R. B. Woodward, R. Hoffmann, *J. Am. Chem. Soc.* **1965**, *87*, 395 (b) R. B. Woodward, R. Hoffmann, *J. Am. Chem. Soc.* **1965**, *87*, 2046 (c) R. B. Woodward, R. Hoffmann, *Acc. Chem. Res.* **1968**, *1*, 17 (d) R. B. Woodward, R. Hoffmann, *Angew. Chem. Int. Ed.* **1969**, *8*, 781

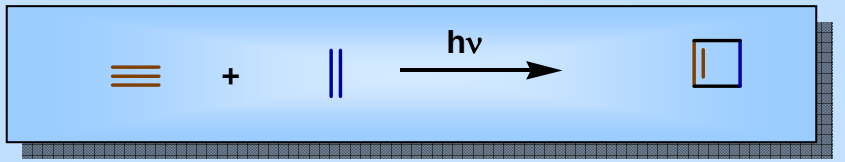
1) PHOTOCYCLOADDITION

- [2+2] photocycloadditions :

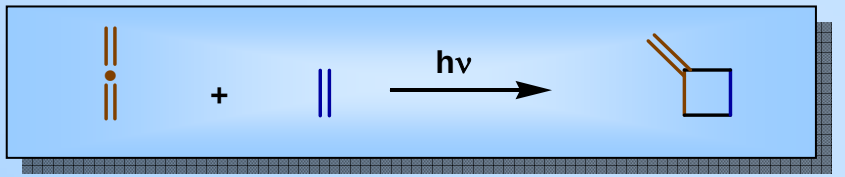
with 1 alkene and 1 α,β–unsatured carbonyl :



with 1 alkyne and 1 alkene :

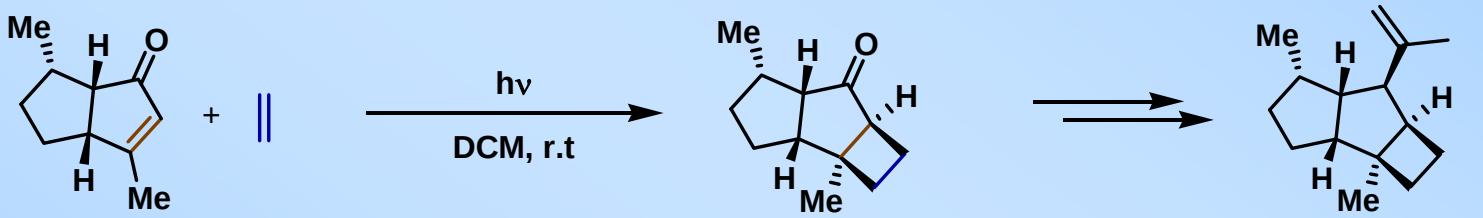


with 1 allene and 1 alkene :

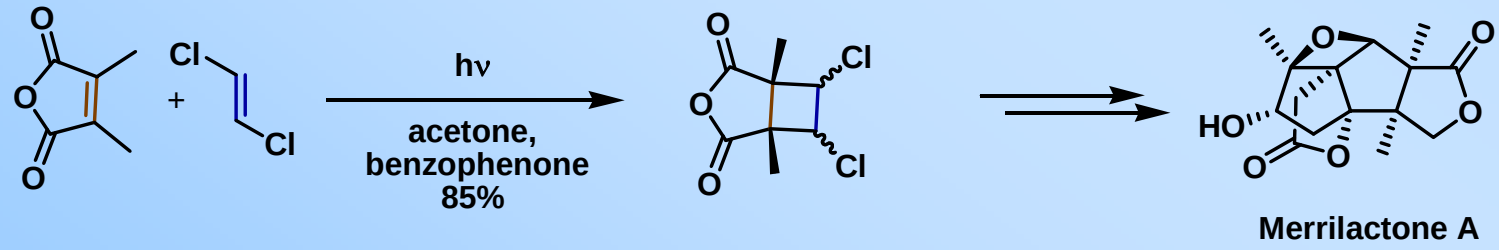


a.1) Cyclobutane-containing natural product :

[2+2] Intermolecular



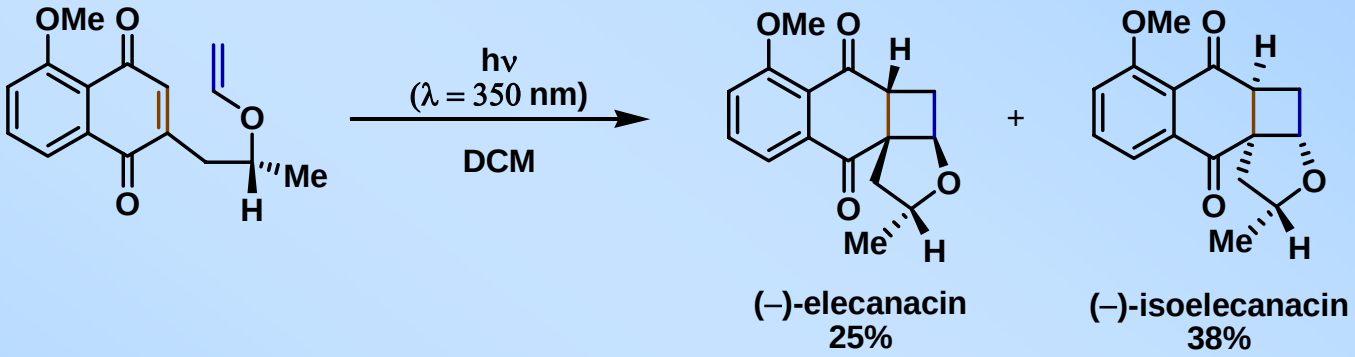
E. Piers, A. Orellana, *Synthesis.* **2001**, 2138



M. Inoue, T. Sato, M. Hirama, *J. Am. Chem. Soc.* **2003**, *125*, 10772

a.1) Cyclobutane-containing natural product :

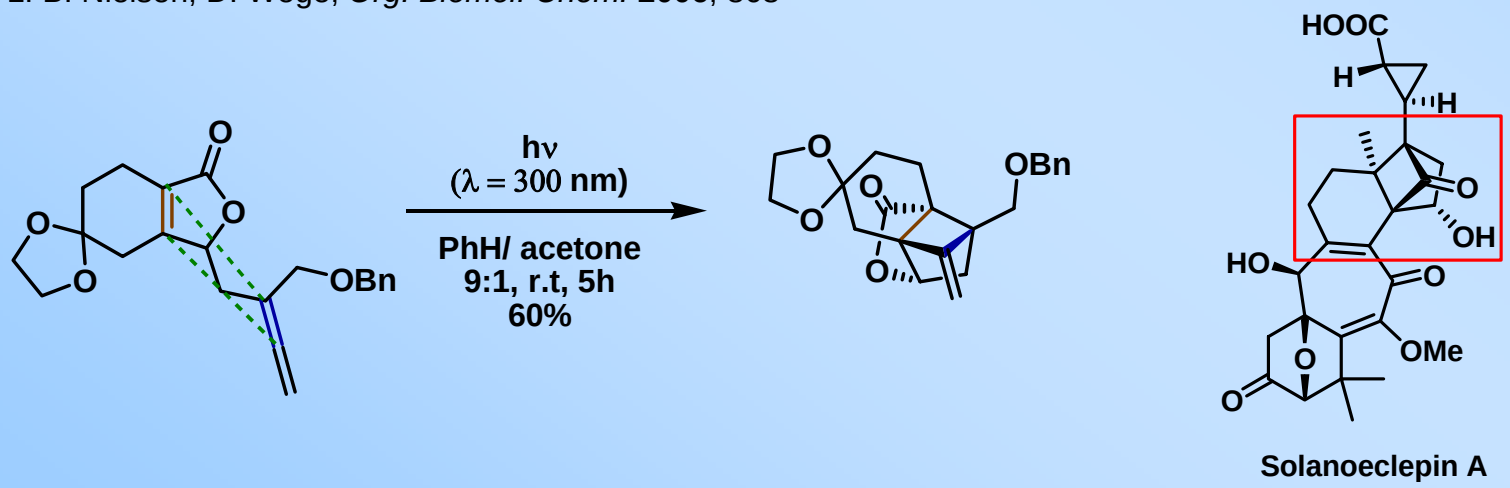
[2+2] Intramolecular



(–)-elecanacin
25%

(–)-isoelecanacin
38%

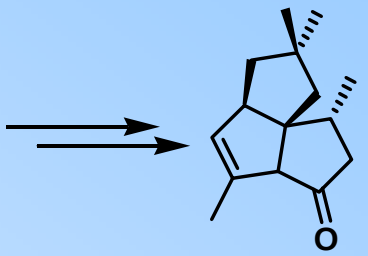
L. B. Nielsen, D. Wege, *Org. Biomol. Chem.* **2006**, 868



Solanoeclepin A

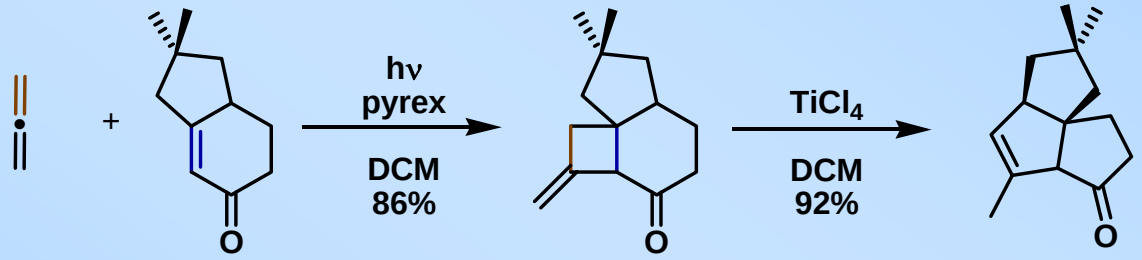
B. T. B. Hue, J. Dijkink, S. van Schaik, J. H. van Maarseveen, H. Hiemstra, *Eur. J. Org. Chem.* **2006**, 127

a.2) Cyclobutane fragmentation :

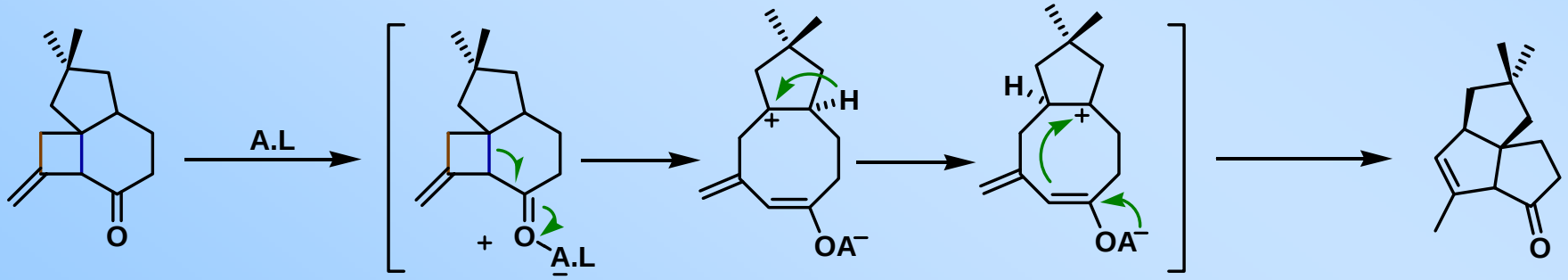


(±)-pentalenene

[2+2] Intermolecular



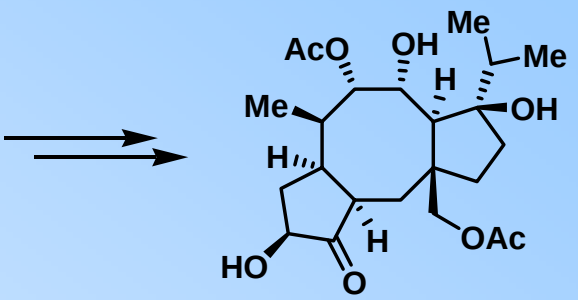
Mechanism :



T. Morimoto, T. Horiguchi, K. Yamada, K. Tsutsumi, H. Kurosawa, K. Kakiuchi, *Synthesis.* **2004**, 753

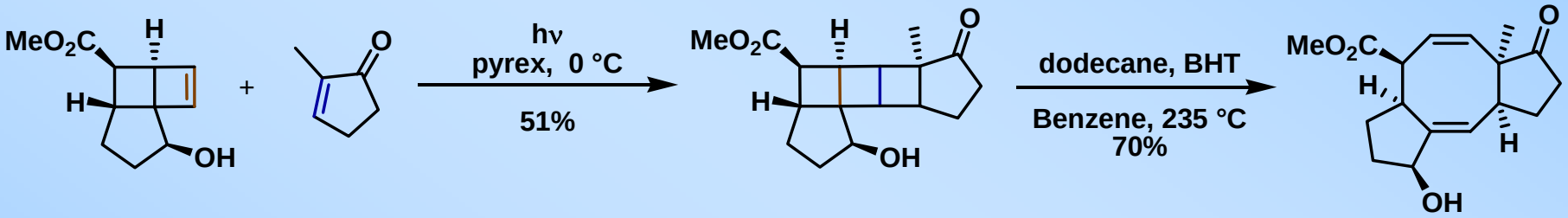
1) PHOTOCYCLOADDITION

a.2) Cyclobutane fragmentation :

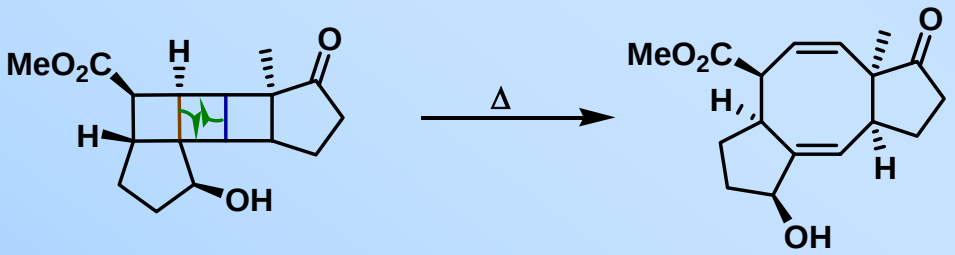


Fusicoplagin A

[2+2] Intermolecular

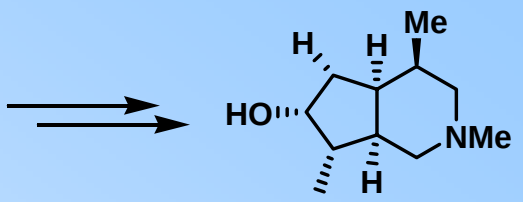


Mechanism :



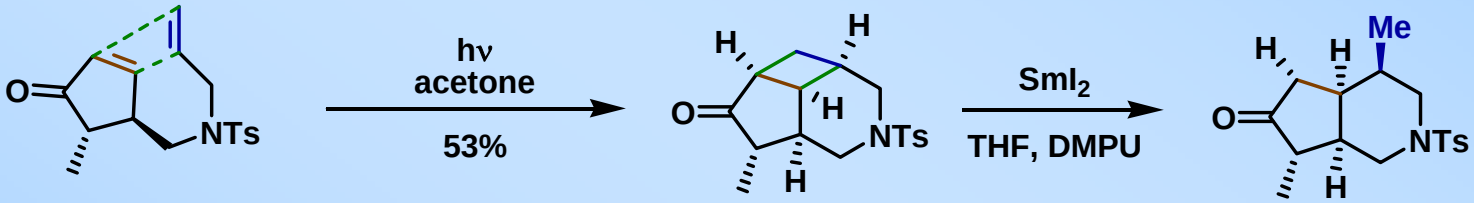
M. L. Randall, P. C. K. Lo, P. J. Bonitatebus Jr, M. L. Snapper, *J. Am. Chem. Soc.* **1999**, *121*, 4534
P. C. K. Lo, M. L. Snapper, *Org. Lett*. **2001**, *3*, 2819

a.2) Cyclobutane fragmentation :

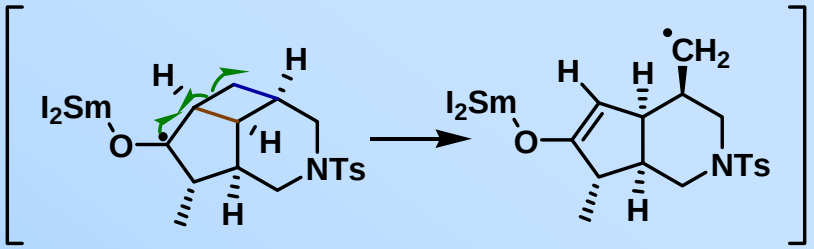


(–)-incarvilline

[2+2] Intramolecular



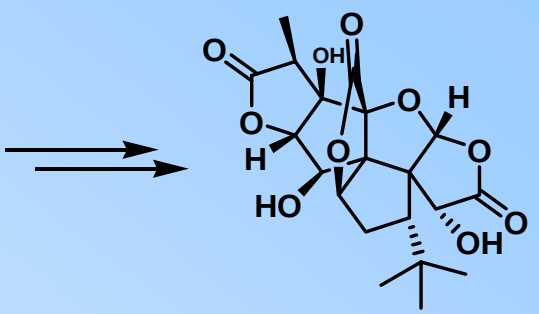
Mechanism :



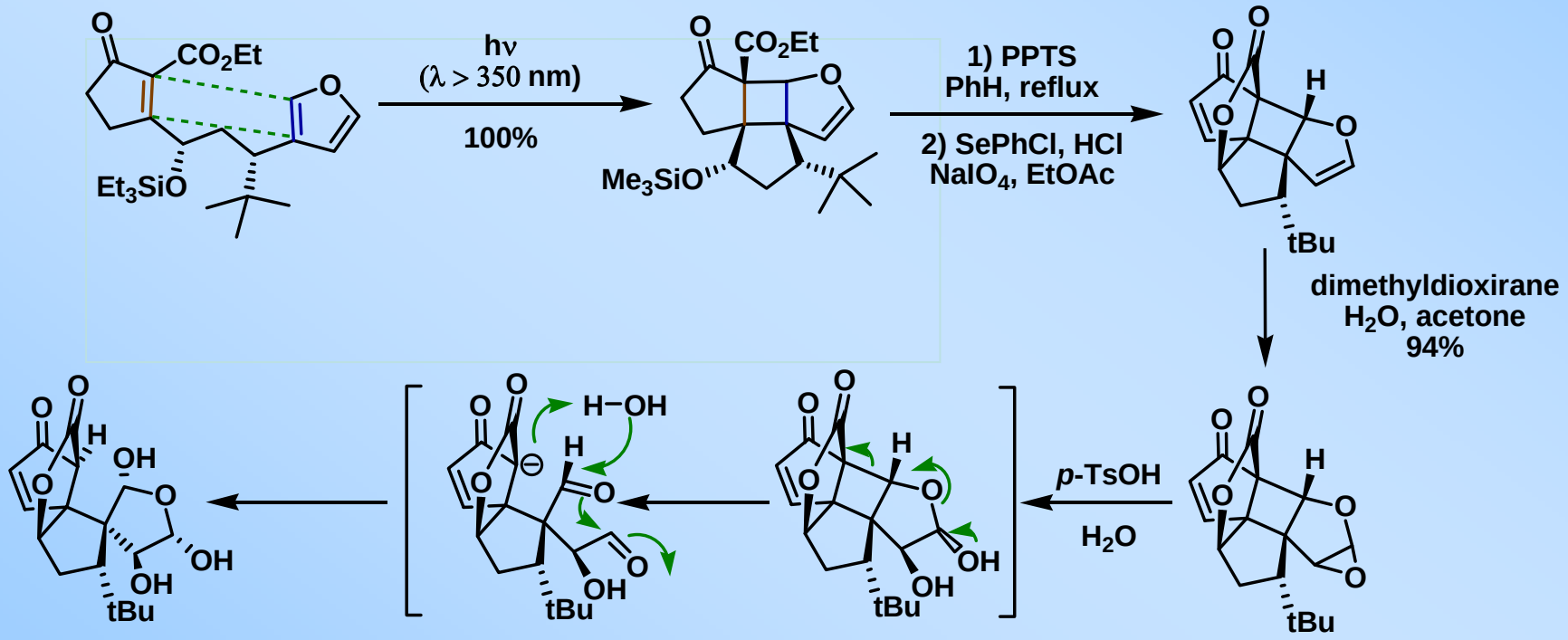
M. Ichikawa, S. Aoyagi, C. Kibayashi, *Tetrahedron Lett.* **2005**, *46*, 2327

1) PHOTOCYCLOADDITION

a.2) Cyclobutane fragmentation :

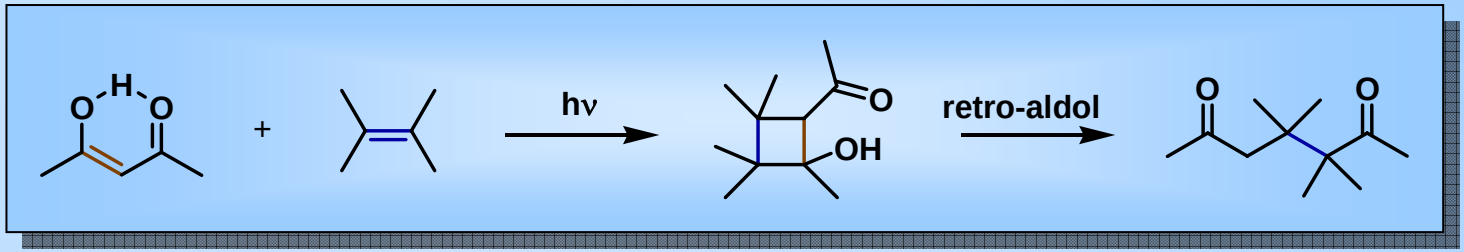


[2+2] Intramolecular



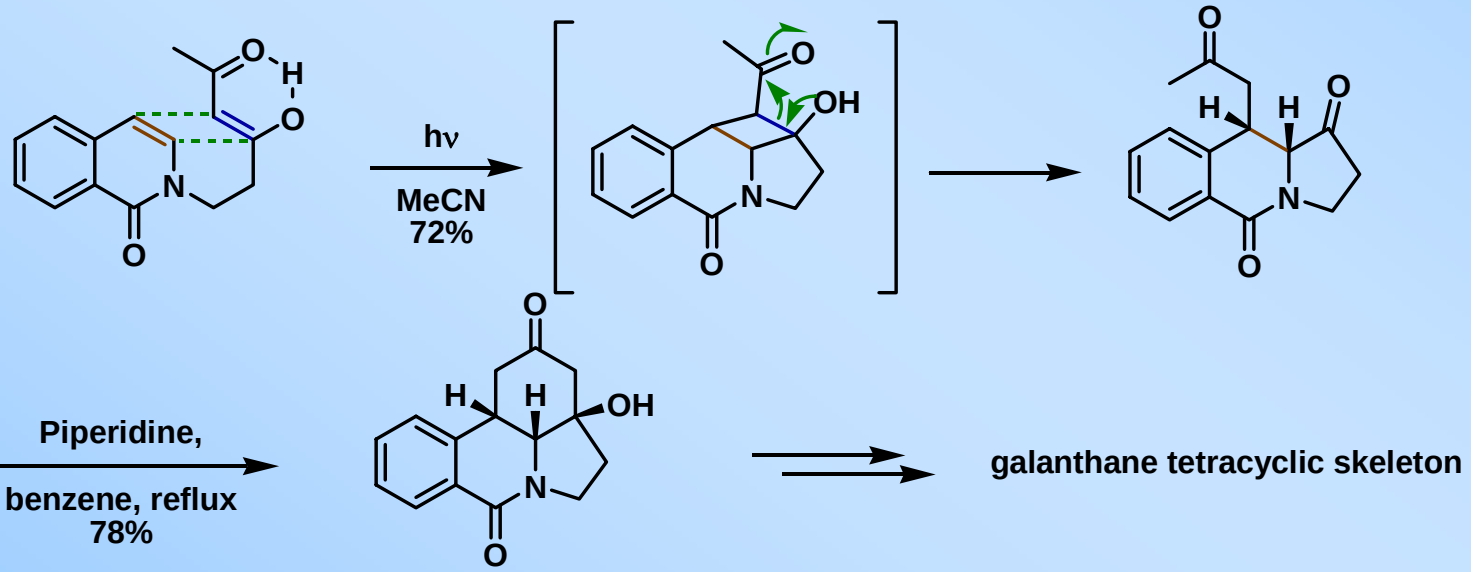
M. T. Crimmins, J. M. Pace, P. G. Nantermet, A. S. Kim-Meade, J. B. Thomas, S. H. Watterson, A. S. Wagman, *J. Am. Chem. Soc.* **2000**, *122*, 8453

a.3) The De Mayo reaction :



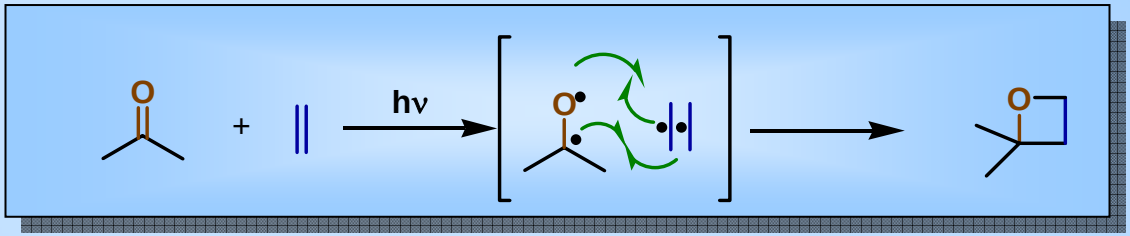
P. De Mayo, H. Takeshita, A. B. M. A. Sattar, *Proc. Chem. Soc. London.* **1962**, 119
P. De Mayo, H. Takeshita, *Can. J. Chem.* **1963**, *41*, 440

Example :



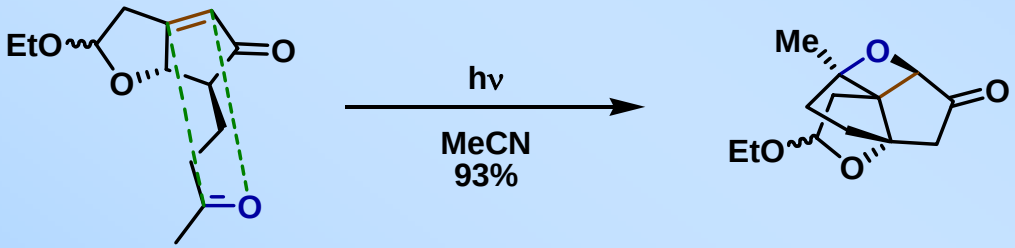
D. E. Minter, C.D. Winslow, *J. Org. Chem.* **2004**, *69*, 1603

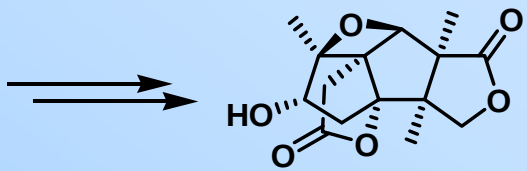
a.4) The Paternò-Büchi reaction :



E. Paternò, G. Chieffi, *Gazz. Chim. Ital.* **1909**, *39*, 341

Example :

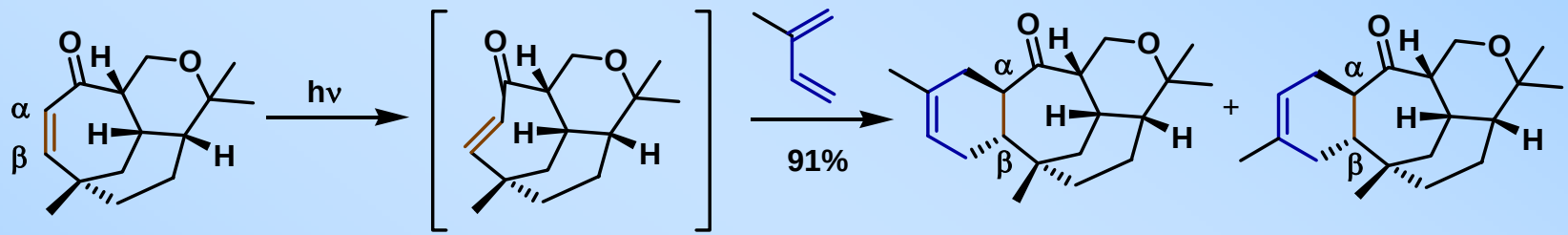


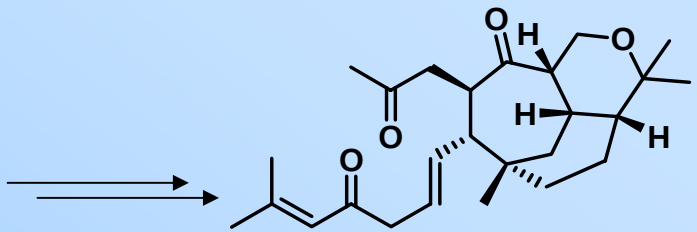


Merrilactone A

J. Iriondo-Alberti, J. E. Perea-Buceta, M. F. Greaney, *Org.Lett.* **2005**, *7*, 3969

b) [4+2] photocycloadditions :

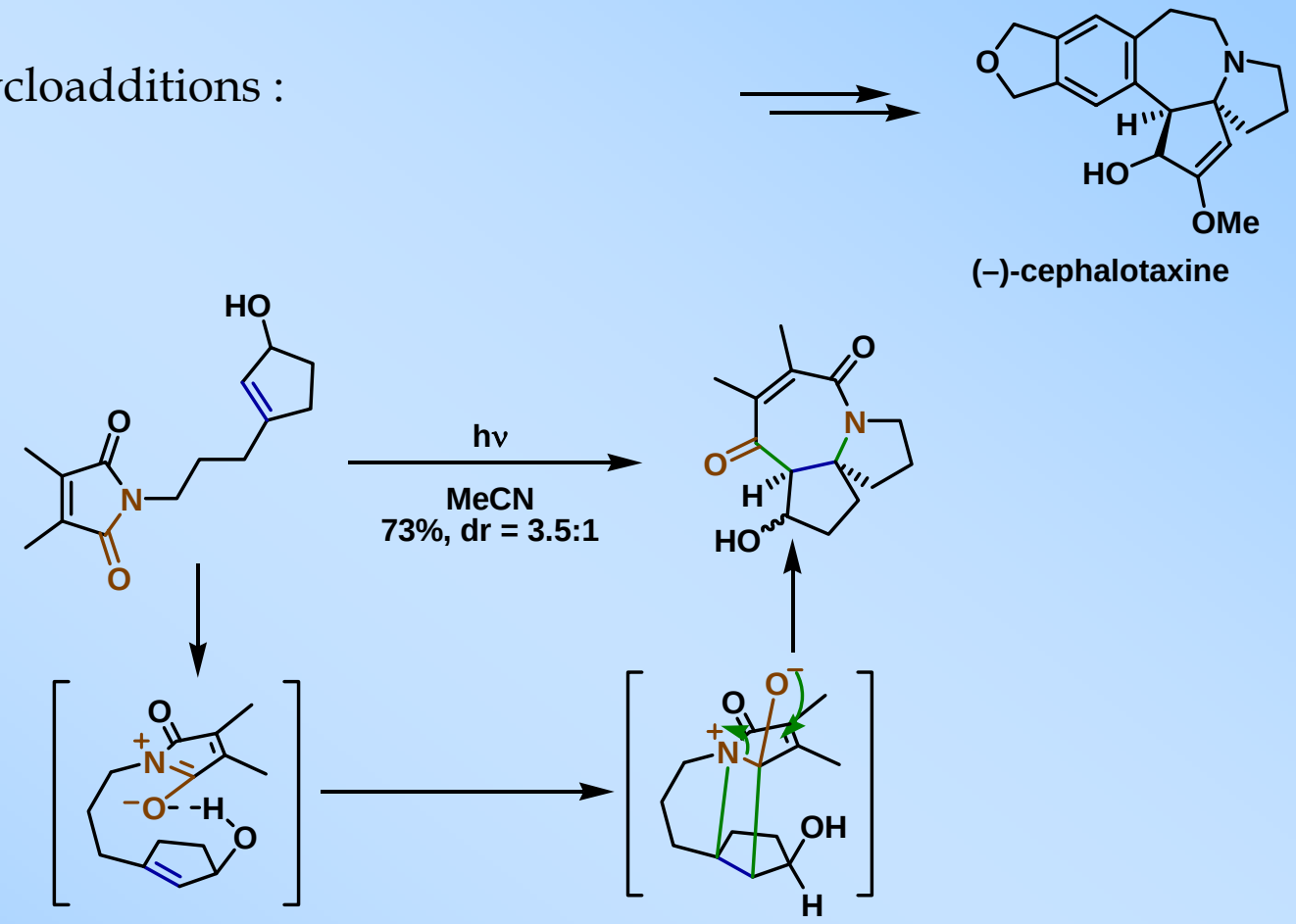




(±)-5-*epi*-10-*epi*-Visbarin E

H. M. L Davies, O. Loe D. G. Stafford, *Org.Lett.* **2005**, *7*, 5561

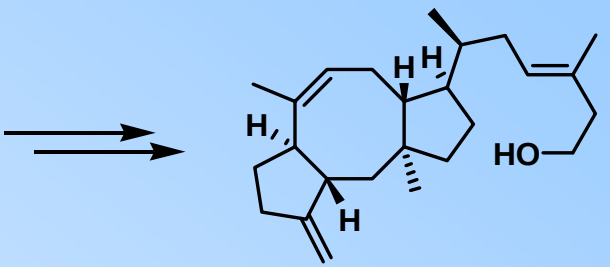
c) [5+2] Photocycloadditions :



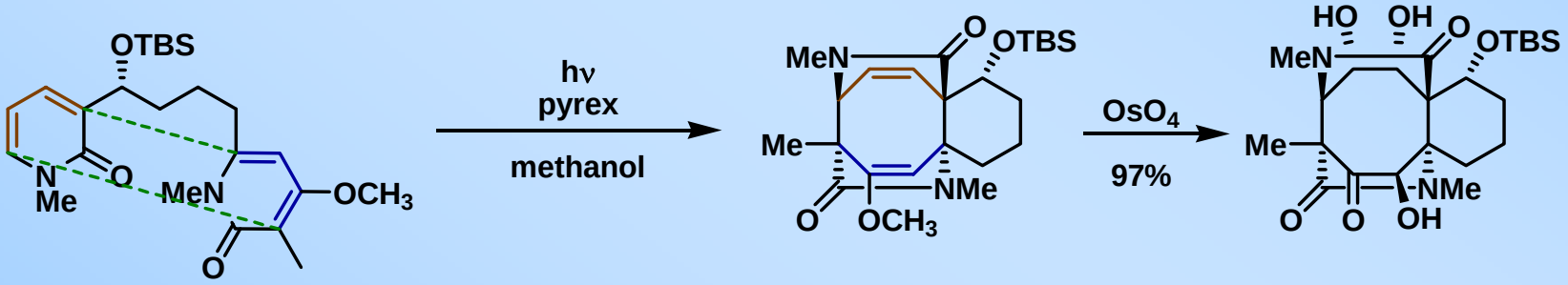
K. I. Booker-Milburn, L. F. Gray, C. E. Anson, S. D. Guile, *Org.Lett.* **2001**, *3*, 3005

1) PHOTOCYCLOADDITION

c) [4+4] Photocycloadditions :



Ceroplastol

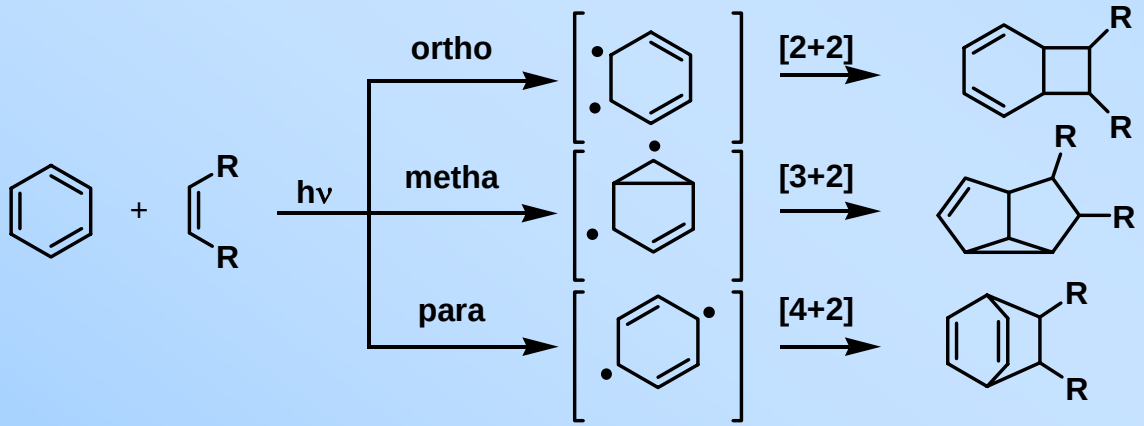


Y.-g. Lee, K. F. McGee, Jr, J. Chen, D. Rucando, S. M. Sieburth, *J. Org. Chem.* **2000**, *65*, 6676

d) photocycloadditions with aromatic compound :

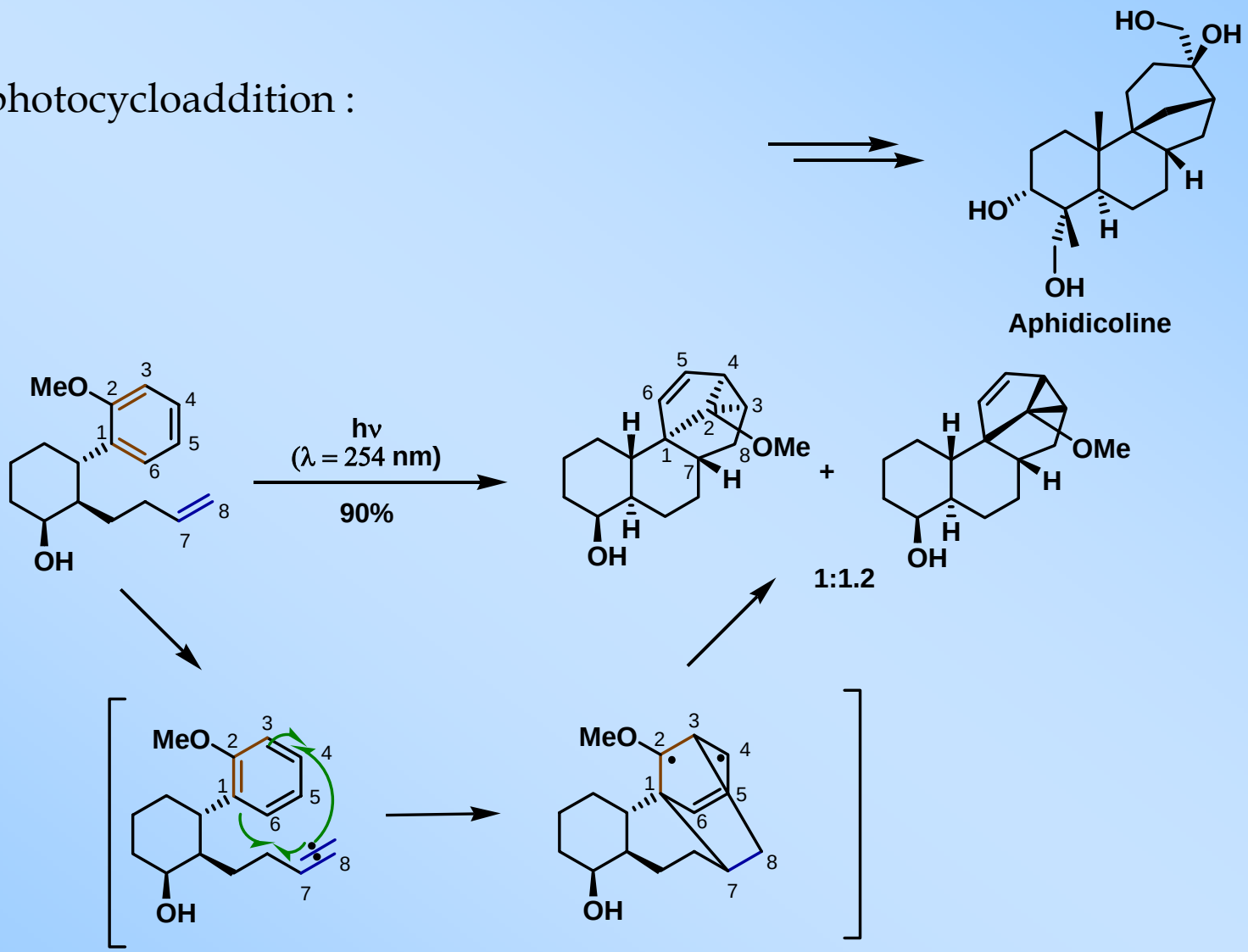
for these compounds :

- a strong tendency to lose aromaticity at the excited state
- 3 types of photocycloaddition [2+2], [3+2], [4+2]



1) PHOTOCYCLOADDITION

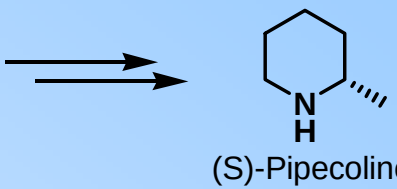
[3+2] photocycloaddition :



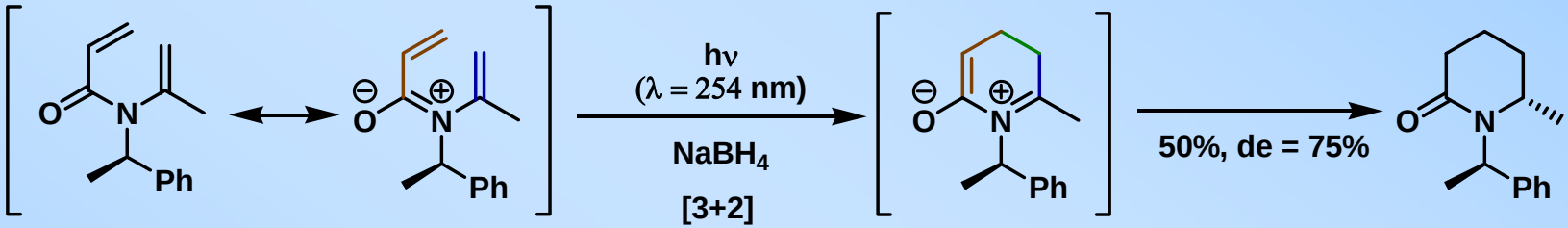
J. W. Boyd, N. Greaves, J. Kettle, A. Russel, J. W. Steed, *Angew. Chem. Int. Ed.* **2005**, *44*, 944

2) REARRANGEMENTS

a) Example of pericyclic reaction :

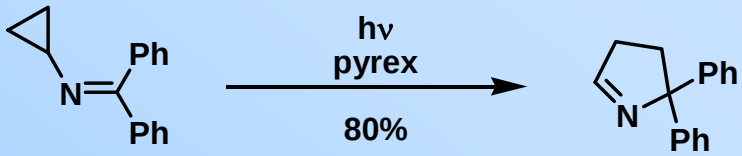


(S)-Pipecoline



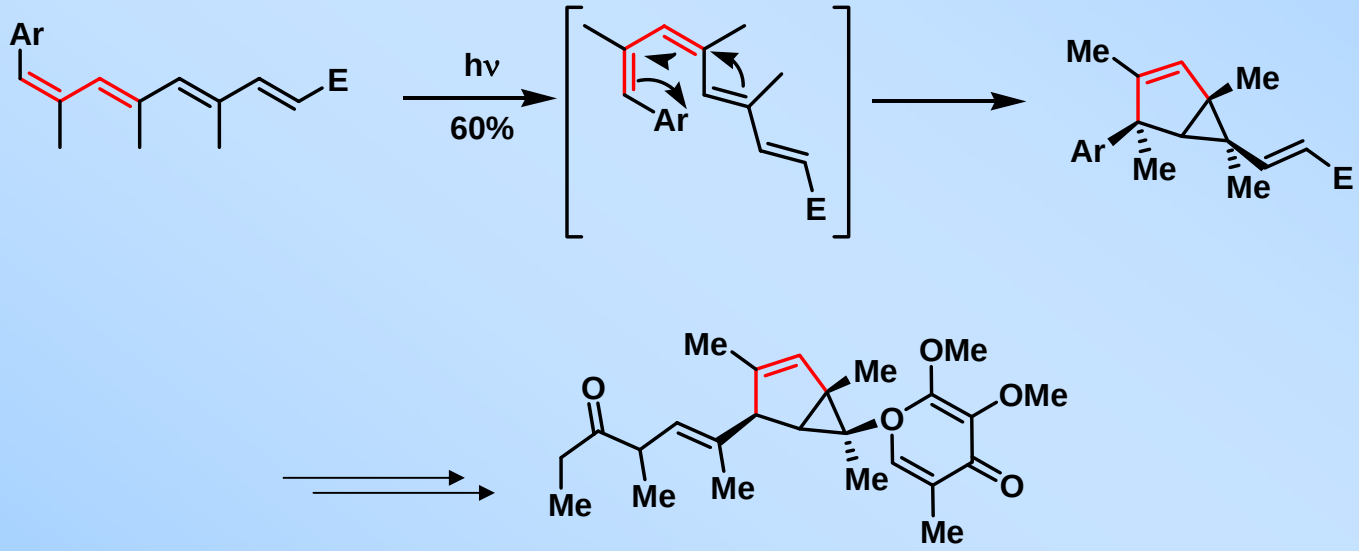
F. Bois, D. Gardette, J.-C. Gramain, *tetrahedron. Lett.* **2000**, *122*, 8769

- transformation of cyclopropylimine into pyrroline :



D. Sampedron, P. J. Campos, A. Soldevilla, M. A. Rodriguez, M. Olivucci, *J. Am. Chem. Soc.* **2005**, 127, 441

b) [4+2] photorearrangement :

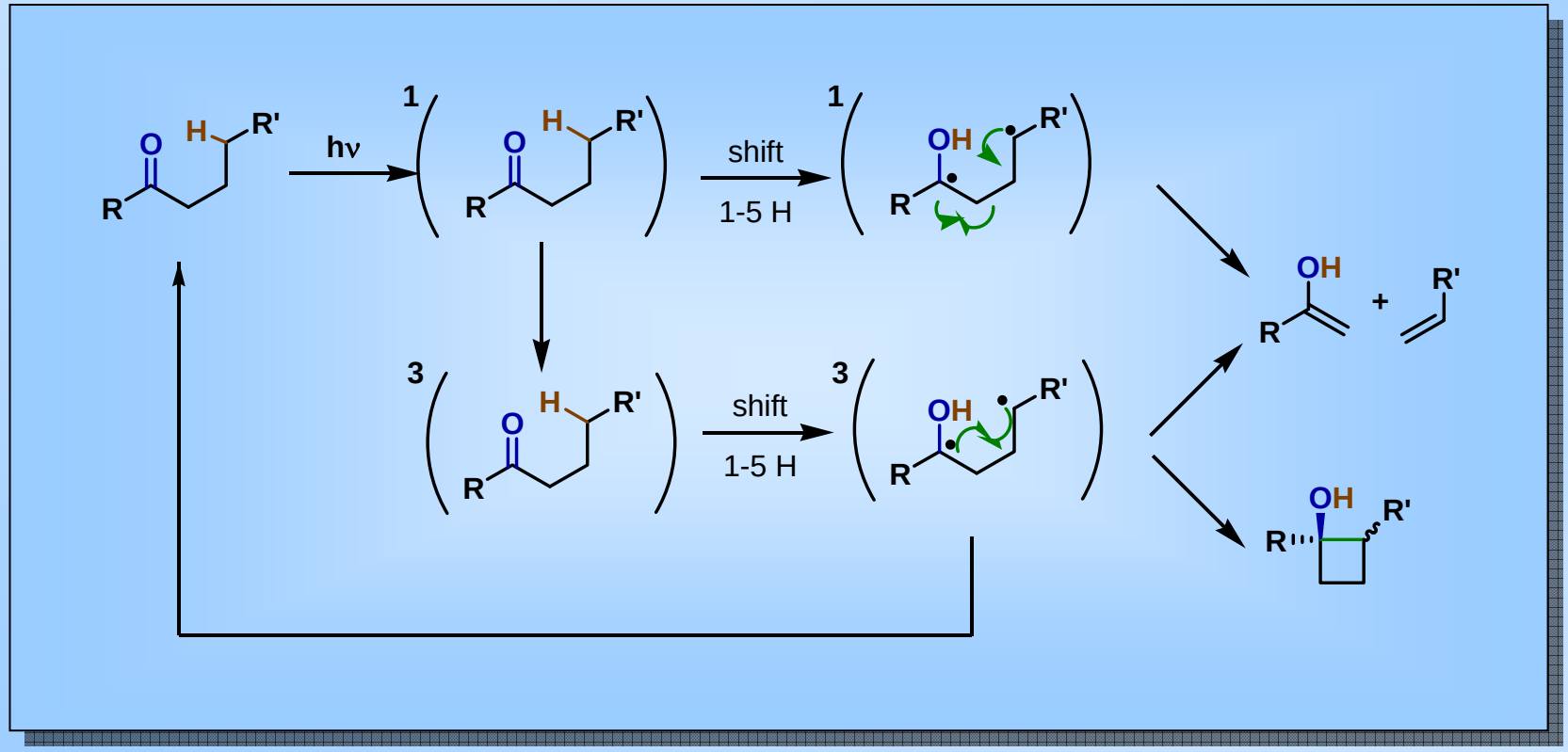


crispatene

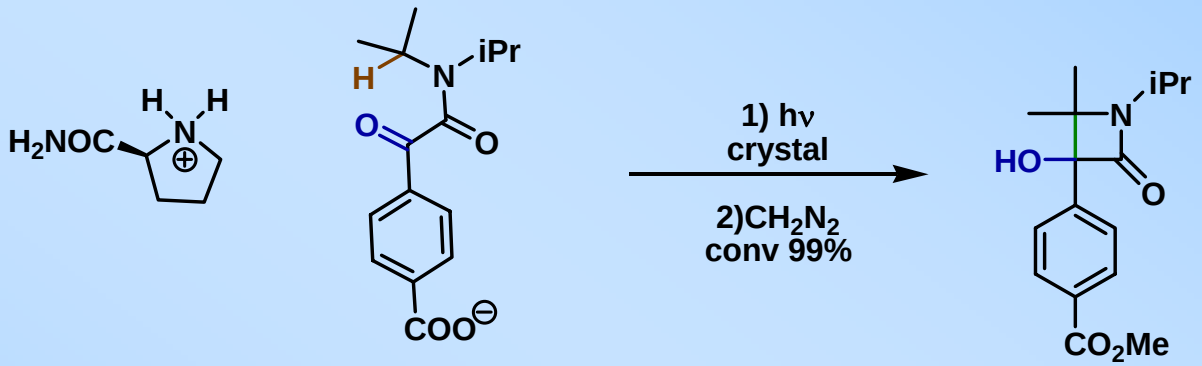
J. E. Moses, J. E. Baldwin, R. Marquez, R. M. Adlington, T. D. W. Claridge, B. Odell, *Org.Lett.* **2003**, *5*, 661

2) REARRANGEMENTS

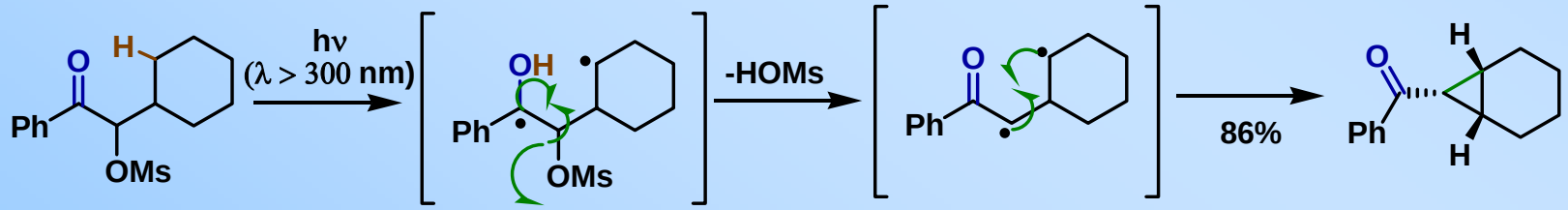
- Norrish-Yang reaction : H atom in the γ position



- Norrish-Yang reaction : examples



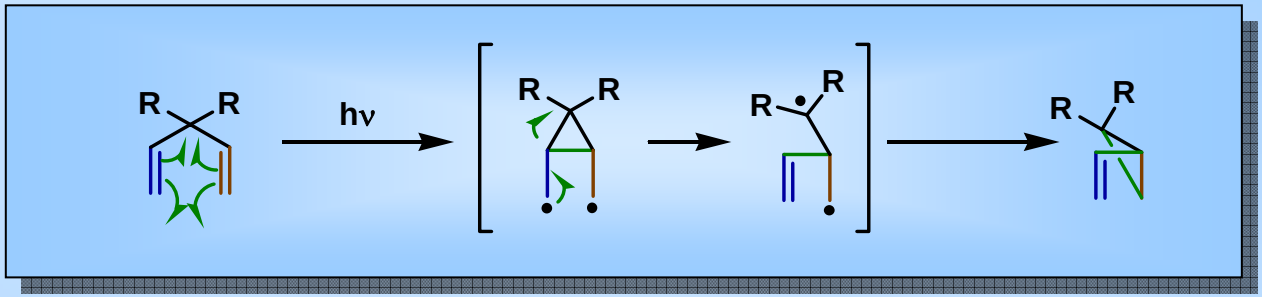
J. R. Scheffer, K. Wang, *Synthesis.* **2001**, 1253



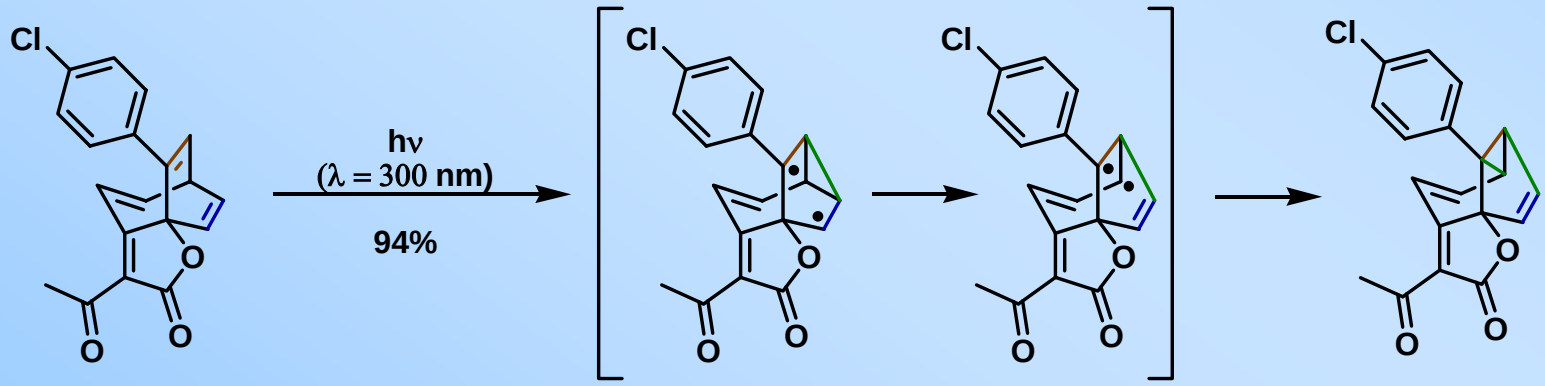
P. Wessig, O. Mühling, *Angew. Chem. Int. Ed.* **2001**, *40*, 1064

2) REARRANGEMENTS

- di-π–methane rearrangement :

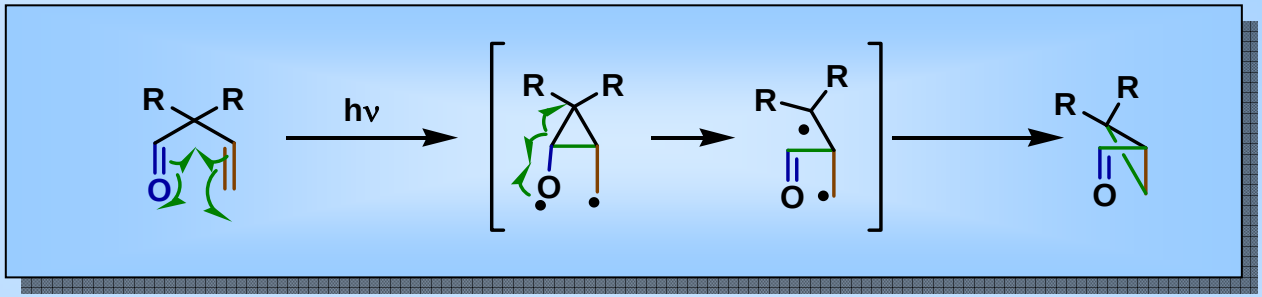


- Examples :

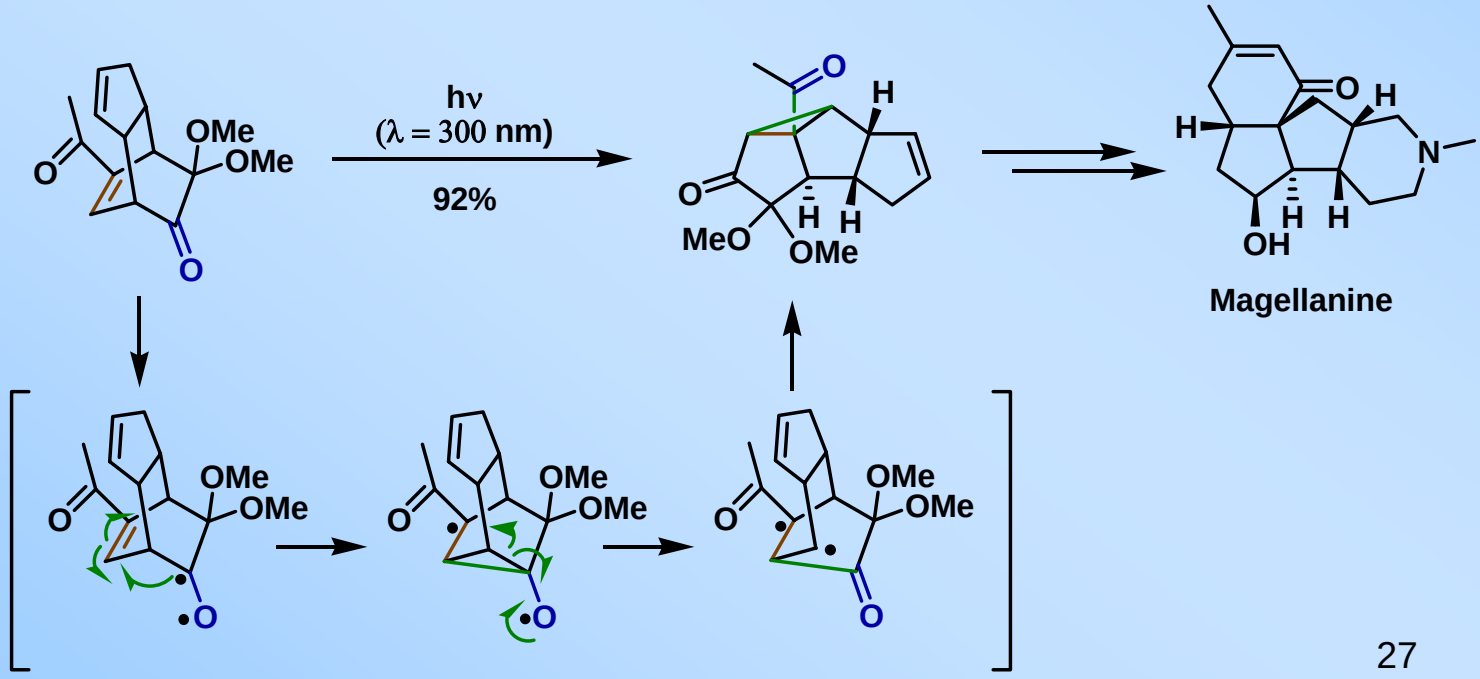


V. Nair, M. V. Nandakumar, G. N. Anikumar, D. Maliakal, M. Vairamani, S. Prabhakar, N. P. J. Rath, *J. Chem. Soc. Perkin Trans. 1.* **2000**, 3795

- oxa di-π–methane rearrangement :



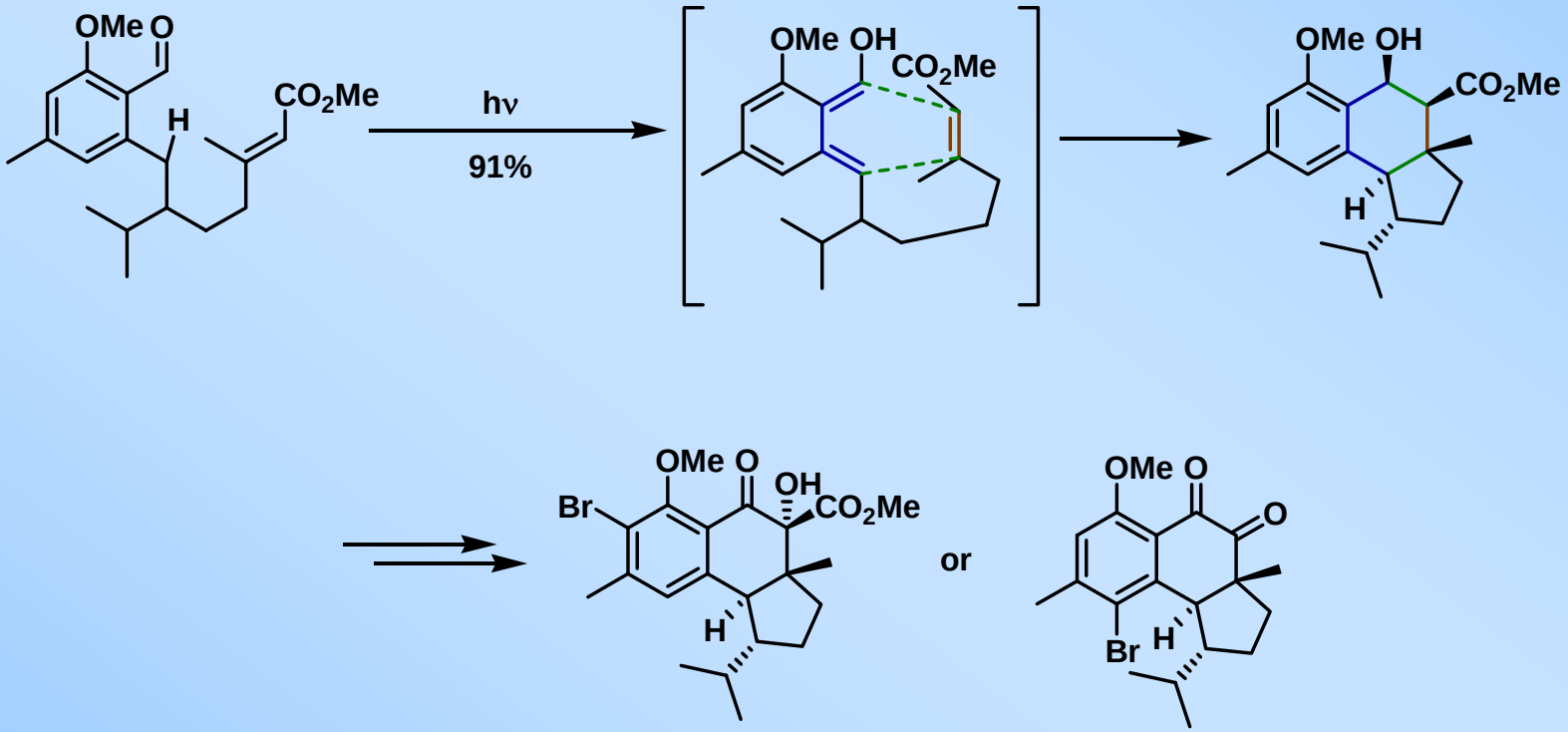
- Examples :



C.-F, Yen, C.-C, Liao, *Angew. Chem. Int. Ed.* **2002**, *41*, 4090

2) REARRANGEMENTS

- example of hydroxyquinodimethane derivative



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Conclusions

- access to polycyclic complex molecules
- installation of quaternary carbons atoms
- stereocontrol of multiple stereocenter
- powerfull set of fragmentation

Perspectives

- asymmetric reaction
- using solar ligth for green chemistry

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